CLIC main beam quadrupole active pre-alignment based on cam movers

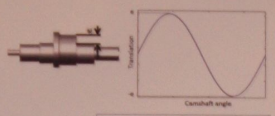
Abstract

Compact Linear Collider (CLIC) is a study for a future 48 km long linear electron-positron collider in the multi TeV range. Its target luminosity can only be reached if the main beam quadrupoles (MB quads) are actively pre-aligned within 17 µm in sliding windows of 200 m with respect to a straight reference line. In addition to the positioning requirement, the pre-alignment system has to provide a rigid support for the nano-stabilization system to ensure that the first eigenfrequency is above 100 Hz.
Re-adjustment based on cam movers was chosen for detailed studies to meet the stringent pre-alignment requirements. There are four different types of MB quads in CLIC. Their lengths and masses vary so that at least two types of cam movers have to be developed. The validation of the cams with less stringent space restrictions has proceeded to a test setup in 5 degrees of freedom (DOF). Prototypes of the more demanding, smaller cams have been manufactured and they are under tests in 1 DOF. This poster describes the challenges, test methods and results as well as current status of development of both cam based system types.

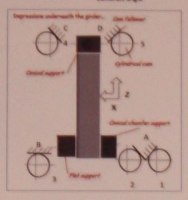
System requirements and overview

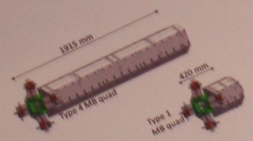
To reach the CLIC pre-alignment target, each MB quad should be actively re-adjusted with micrometric precision in 5 DOF (all except longitudinal translation). In addition, the pre-alignment system should provide rigid support for the nano-stabilization system. Cam movers were chosen as actuators for the pre-alignment system.

Cam mover
Cam movers are actuators in which translation is realized by rotating an eccentric camshaft. Cam mover's stroke is twice the eccentricity.



5 DOF Configuration
5 DOF movement can be realized using 5 cam movers and interfaces as shown in the schematic (figure) in the right. There are 4 interfaces with ground for higher stiffness.





5 DOF Configuration
There are two CLIC MB quad types. They both need their own cam mover design.

Type 1

Space restriction creates additional challenges compared to type 4. Mainly, there is enough space for 1 gearbox instead of 2. This is critical because cam mover's resolution depends on:

- Gear ratio
- Stepper motor resolution
- Eccentricity (fixed to have enough stroke)

Design
Theoretical worst case resolution of 0.35 µm was achieved with:

- Davall Gears custom 90:1 Spriradrive gearbox
- Oriental Motor [illegible] UPMA-A7 stepper motor (500 steps/rev)

Spiradrive gearbox
A prototype cam mover was built and installed in the 1 DOF mock-up. First tests showed good results but the pinion of the gearbox broke down after short period of testing.

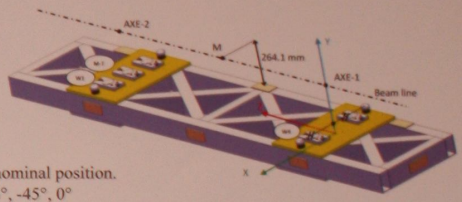
- The 1 DOF mock-up's structure causes some sticking which causes high momentary torque in the gearbox
- The pinion was made of bronze to have negligible backlash
- Steel pinion is under development in parallel
  - More robust but introduces up to 7 µm of backlash
- Tests in 5 DOF mock-up (currently being designed) finally determine which pinion material is better

Type 4

ZTS cam mover (ZCM)
Cam mover design was optimized together with the company ZTS VVU Kosice which also manufactured the cam movers for the 5 DOF mock-up.

5 DOF mock-up
5 DOF mock-up was built for the final validation of the cam mover based pre-alignment concept.

- Re-positioning accuracy
- Natural frequency measurements



Operation principle
Movements are relative to a so called nominal position.

- ZCM angles: -45°, -135°, -135°, -45°, 0°
- The angles are chosen so that the control algorithm is as simple as possible

Chassis orientation is measured using two WPSs (Wire Position Sensor) installed around a stretched wire and a high resolution inclinometer.

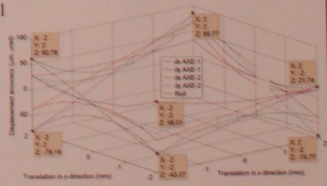
- WPS resolution 0.1 µm, inclinometer resolution < 1 µrad
- WPS measures both x- and y-offset of the stretched wire
- Another stretched wire and two associated WPSs are installed for redundancy

Control algorithm
The core of the 5 DOF mock-up control algorithm are Dr. Andreas Streun's formulas.

- The formulas transform point M orientation (in 5 DOF) to required cam angles
- User inputs (reference position) are x- and y-displacements in points AXE-1 and AXE-2 as well as chassis roll (rotation around z-axis)
- The user inputs are transformed to point M orientation for cam angle calculation
- WPS offsets (W1, W4) are transformed to x- and y-displacements in points AXE-1 and AXE-2
- Inclinometer (M-T) provides directly the chassis roll

Test results

- Movement resolution < 1 µm
- Repeatability < 5 µm (dx, dy), < 5 µrad (roll)
- Displacement accuracy (deviation between required and measured relative orientation):
  - Short and simple movements: 10-20 µm/µrad
  - Complex movements: significantly worse
- Displacement accuracy of below 1 µm and 5 µrad achieved using automatic iteration
  - Simple movements: 2-3 iterations (loaded)
  - Complex movements: mostly below 10 iterations (loaded)
  - Significantly better without load weight



Improvement potential
The 5 DOF mock-up re-positioning system could potentially be improved by:

- Making the mathematical model more accurate (parameter optimization or look-up table)
- Improving the iteration algorithm (micrometric movements in one direction cause parasitic movement in another direction
- Potentially real time position control with faster data acquisition electronics

Conclusions

The 5 DOF mock-up showed that a cam mover based system meets precision requirements in the case of CLIC type 4 MB quad. The mock-up's natural frequencies will also be measured and these results will finally determine whether the system is applicable or not. The 5 DOF mock-up is now being dismantled. The ZCM bearings will be changed to another type and afterwards the mock-up will be rebuilt and re-tested.
Designing a cam mover for the type 1 pre-alignment system has proven to be challenging due to the additional size restrictions. Two gearbox designs are being studied in parallel and a 5 DOF mock-up is under design at the moment.

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